mat - an ICT application to support a more sustainable use of print products and ICT devices

Hischier, Roland ; Keller, Michael ; Lisibach, Rudolf ; Hilty, Lorenz

Abstract: Digital information and communication devices –smartphones or tablet, laptop and desktop computers– are often perceived as much more environmentally friendly than newspapers and magazines – but is this common opinion justified? Previous studies comparing the environmental impact of electronic vs. print media show that the answer depends on many parameters of the technologies under study and the use patterns assumed. Empa's Technology and Society Lab, the University of Zürich the "Denkfabrik visuelle Kommunikation" jointly developed a web-based tool that can be used to evaluate the environmental effects of a broad variety of printed and electronic media for clearly defined use patterns. In a first step, the basic scientific facts were established using the life cycle assessment (LCA) methodological framework. Two LCA studies have been done, one for the production and disposal of the various media, the other one for the (active) use of each of these media. Technical data from various producers have been used for the ICT devices examined as well as for the power consumption during the use phase. All inputs to these processes have been modeled using background processes from the ecoinvent database. The results from these two studies are environmental indicators for each type of media representing production and disposal resp. (active) use of the device, calculated per device resp. per unit of active use. Combining these data in the second step made it possible to calculate the environmental impacts from any specific use pattern combined with the various types of print and electronic media. In order to make those findings available to users who have no knowledge in LCA methodology, a website providing an easily applicable tool has been developed. Two cases studies – one comparing different ways of advertising for (food) products; the other one taking the conference paper at hand as example – show some of the possibilities this tool offers to non-specialists.

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ABSTRACT

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Two cases studies – one comparing different ways of advertising for (food) products; the other one taking the conference paper at hand as example – show some of the possibilities this tool offers to non-specialists.

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Keywords

Life Cycle Assessment (LCA), electronic media, printed media, webtool.

1. INTRODUCTION

The use of electronic instead of printed media is usually considered more sustainable. In a recent project, on behalf of the "Denkfabrik visuelle Kommunikation" of viscom (the Swiss Association for Visual Communication), Empa's Technology and Society Lab, together with the Department of Informatics (IFI) of the University of Zürich, developed the web-based tool **mat** (media analytics tool) that can be used to evaluate the environmental effects of a broad variety of printed and electronic media for clearly defined use patterns. While Empa took care of the life cycle models and data, IFI was in charge of the development and implementation of the web-based tool.

This project is part of many years of research at Empa's Technology and Society Lab in assessing and reducing the environmental impact of communication (see e.g.[1-6]).

This paper describes in a first part (chapter 2) the scientific basis, starting point for the data integrated into the web-based tool, which is described in chapter 3. Two case studies showing the application of the tool are briefly presented in chapter 4, followed by concluding remarks.

2. SCIENTIFIC BASIS

2.1 Life Cycle Assessment

The objective of the first part of this work was to establish the model and data base for all subsequent steps. For this, a life cycle assessment (LCA) study has been conducted. LCA is a comprehensive framework that quantifies ecological and human health impacts of a product or system over its complete life cycle. This framework can be applied to any kind of product and to any decision where environmental impacts are of interest. Nowadays, LCA is applied by a broad variety of actors – from governmental organisations to industry, often with support from specialized research and/or consulting organisations. Reasons for this wide application can be found e.g. in the clear guidance for the application provided by the ISO 14'040, 14'044 standards [7,8],

as well as the considerable amount of databases available today (see e.g. [9] for an overview), which allows fast screenings of products or services.

Within this framework, the ISO standard distinguishes between four steps – i.e. goal & scope definition, inventory analysis, impact assessment and interpretation –; described in the following chapters 2.2 to 2.5 for the current study here.

2.2 Goal & Scope

The overall goal of the study is the calculation of the ecological load due to the use of printed and electronic media in the context of a variety of use cases. In a first phase, our objective is the calculation of the environmental impact from the production and disposal of various (printed and electronic) media; as well as the calculation of the impact due to '1 unit use' of the respective medium. These data can then be used to calculate various application cases in the second part of the project. In order to achieve the objectives of the first phase, two distinct LCA studies have been performed, producing the necessary input data for the web-based tool (see chapter 3).

The first LCA study deals with production and disposal of the various (printed and electronic) media. For this case, "classic" cradle-to-gate LCA studies could be applied to the various electronic devices and printing technologies. In Figure 1, these system boundaries are shown for the example of a desktop computer.

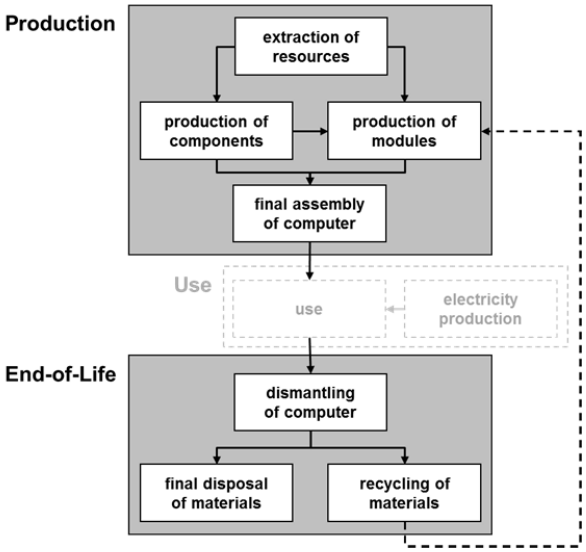

Figure 1. System boundaries of the system "desktop computer" as an example

As a functional unit, this first LCA study is using the complete device in the case of electronic media; i.e. one desktop computer (including keyboard and monitor screen). For the print media, a functional unit of 1'000 kg of printed matter is used.

The second LCA study has its focus on the (active) use phase. Apart from the electricity consumption due to the use of an electronic medium, this second study defines how the results from the first study (i.e. production, disposal of the devices) are taken into account per unit of use. Figure 2 shows the various elements of this system for the example of a smartphone.

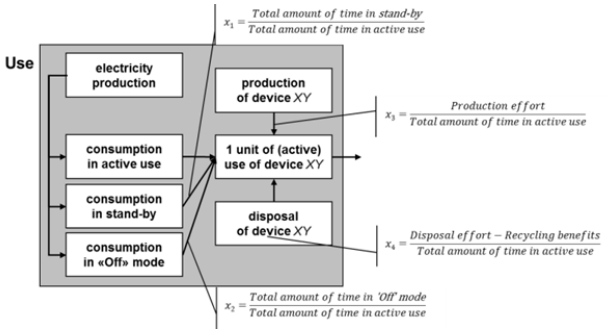

Figure 2. System boundaries and formulas for the calculation of 1 unit of use of an electronic device

The functional unit for electronic media chosen in this second LCA study is '1 hour of (active) use'. In the case of printed matter, the functional unit is '1 kg of print products' (which can be calculated from the format and the square weight of the used paper type).

2.3 Inventory Analysis

2.3.1 Production of electronic media

On the level of data, composition data from various producers have been used in order to establish the composition tables of the various examined ICT devices. Table 1 shows an overview.

Table 1. Overview of the used data sources for the modeled electronic devices

Smartphone	▪ Weight: 136g (average weight of 5 "best" smart-phones in 2011 according to [10]) . ▪ Composition data: mix of data about iPhone 3 and iPhone 4S, taken from [11,12].
Tablet (I)	▪ 10-inch model with LCD display. ▪ Composition data of iPad 2 used, taken from [13].
Tablet (II)	▪ 10-inch model with an e-paper display ▪ Composition data of iRex 1000 used, taken from [14].
Netbook	▪ 10-inch netbook with an average weight according to a sample of 8 various models of 1.33 kg. ▪ Composition data: extrapolated from composition of laptop computer, assuming a similar composition.
Laptop Computer	▪ Mix of 14-/15-inch laptop computers (Windows, Mac) with an average weight of 2.544 kg. ▪ Composition data: mix of various 14-/15-Inch models (Windows, Mac), taken from [15,16].
Desktop Computer	▪ Original datasets from ecoinvent [17] for 'desktop computer', 'keyboard' and 'LCD screen, 15-inch' used.
LCD TV	▪ Mix of 40-/42-inch LCD television devices, with an average weight according to a sample of 9 various models of 17.4 kg. ▪ Composition data: extrapolated from the composition of an 15-inch LCD computer screen in ecoinvent [17], assuming a similar composition.

Input data for these processes (e.g., data of electronic components and modules, of basic materials, of material processing efforts) have been taken from the ecoinvent database [17], which has provided all the background data for this study. The production efforts have been estimated for all devices based on the respective efforts for the production of a laptop computer as reported in [18].

The resulting input data for the smartphone are shown as an example in Table 2.

Table 2. Example for linking project-specific data with background data from the database ecoinvent v2.2 (data shown for "smartphone")

Material	Amount	Used ecoinvent data
Stainless steel	36.3 g	chromium steel & sheet rolling
Plastics	9.3 g	ABS & injection moulding
Battery	24.5 g	LiIon-Battery
Circuit boards	17.6 g	Printed wiring board, mounted, laptop computer
Display	9.7 g	LCD module
Glass	35.9 g	flat glass, coated
Others	2.7 g	20% silicon, 40% copper (+ wire drawing), 40% aluminium (+ sheet rolling)
Power adapter	50 g	0.11 of dataset 'power adapter, for laptop'
Production efforts	0.072 kWh	Electricity, medium voltage (China)
	70 kg	Tap water & sewage water treatment

2.3.2 *Production of print media*

For the various offset printing processes, the core information (i.e. the consumption and emission values) has been collected from the environmental reports of various German and Austrian printing facilities; the digital printing process is based on a dataset which later became part of ecoinvent v3 (not yet published when this project was established). An overview of all considered facilities and data sources is given in Table 3. For all upstream processes, background data from ecoinvent has been used here as well.

Table 3. Overview of the used data sources for the modeled printing technologies

Offset printing, reel-fed	▪ Unweighted average of environmental data of the printing facilities Axel Springer, Berlin [19] / SDS Medien, Aalen [20] / Nürnberger Presse, Nürnberg [21]
Offset printing, sheet-fed	▪ Unweighted average of environmental data of the printing facilities Druckhaus Berlin Mitte, Berlin [22] / Oktoberdruck, Berlin [23] / Grassl Druck, Bad Vöslau [24] / ABC Druck, Heidelberg [25]
Offset printing, coldset	▪ *Due to a lack of specific data, data from "Offset printing, reel-fed" are used as a proxy*
Digital printing, Inkjet	▪ Data of the dataset for digital printing from the (unpublished) database ecoinvent v3 used.
Digital printing, Electrophotography	▪ *Due to a lack of specific data, data from "Digital printing, inkjet" are used as a proxy*

For paper, the datasets in ecoinvent [17] for newsprint paper, recycling paper, LWC paper, SC paper, woodfree coated as well as woodfree uncoated paper are used.

2.3.3 *Use phase*

For the various electronic media, different use modes with their energy consumption are distinguished. Table 4 summarizes the electric power values resulting for the different use modes.

Table 4. Overview of the energy consumption (in W) of the various use modes for the different electronic media

	Active	Sleep	Off	Remarks / Source
Smartphone	1.1 0.65	0.015	0	2 active mode (high = data / low = voice); data from Alborg University
Tablet (I)	3.16	0.45	0	Apple iPad 2
Tablet (II)	1.43	0	0	Estimated from Kindle
Laptop	17.9	1.33	0.32	Apple 15'' MacBook Air
Netbook	9.3	0.94	0.24	Apple 11'' MacBook Air
Desktop PC	85	30	3.5	[17]
TV	60	0.22	0	www.TopTen.ch

In addition, default use pattern (for the average daily use) as well as the overall life-time of the devices have been established in this first part of the study; the use patterns are summarized in Table 5. These defaults can later be overriden by the user of the tool.

Table 5. Summary of the default use patterns assumed for the different electronic media

	Active [h/d]	Sleep [h/d]	Off [h/d]	Life Span [years]
Smartphone	1+1	22	0	2
Tablets (both)	2	22	0	2
Laptop	4	10	10	4
Netbook	4	10	10	4
Desktop PC	4	10	10	6
TV	2.5	20.5	1	6

Additional infrastructure required to access the Internet is taken into account by using the relevant dataset from ecoinvent described in [26].

For the actual data transfer ecoinvent contains two datasets (both also described in [26]) representing two different data transfer rates (i.e. 0.2 resp. 0.7 Mbit/s); they cover also the impact of the infrastructure (routers). However, these datasets don't contain the impact of the datacenter accessed through the Internet. Based on the estimated energy consumption of all US-based data centers in [27] and the totally transferred data amount in the USA in the same time-span (value taken from [28]), an energy consumption per MB of transferred data in the range of 0.19 to 0.36 Wh can be calculated. We use the mean value 0.275 Wh to add the impact due to datacenter access to the impact due to data transfer over the Internet, which is of 0.2 Wh/MB (average value from the two datasets in ecoinvent [17]; similar to the value reported in [6]).

In addition, the possibility of printing out the information at home or at the workplace is given for the cases of the laptop and the desktop computer (all other devices are mobile; printing is not considered for them). For this, the default dataset of a colour laser printer in ecoinvent [17] is used here; allowing a one-side or both-side print on either type of paper.

For the use of the print media no impact is taken into account (thus, we assume the documents being read without the use of additional lighting equipment). However, various scenarios for the distribution from the printing facility to the client are taken into account – simple "point-to-point" scenarios (using either train, lorry or a sea ship as means of transport by using the relevant data from [17]), a scenario based on the typical mix of van, car and pedestrian transport for the delivery of a newspaper (based on data from [29]) as well as a mix (without sea ship transportation) as a generic scenario.

2.3.4 End-of-Life of various media

For the various electronic devices, an end-of-life treatment in accordance with the European Waste Electrical and Electronic Equipment (WEEE) Directive has been modeled, using the various WEEE treatment datasets in ecoinvent [17], as described in [18]. For this study it is assumed that all devices are manually depolluted and then mechanically treated (i.e. passed in a shredder). For the depollution, the rules from [18] (part V, Tab. 4.6) are used; further mechanical treatment according to the procedure described in [18] (part V, chapter 4.3.5).

In case of printed media a recycling rate of 67% is assumed and the remaining 33% are assumed to be incinerated in a modern municipal solid waste incinerator (data taken from [17], described in detail in [30]).

For all recycled materials, the avoided burden approach is used in this study – i.e. a bonus is given that is equivalent to the environmental load from the primary production efforts for a similar amount of material (i.e. the primary production of steel in a converter furnace), minus the recycling efforts for the material (i.e. the efforts of the secondary steel production in an electric arc furnace). All data for these primary and secondary processes are taken from [17].

2.4 Impact Assessment

At the level of the evaluation of the environmental impacts, a variety of impact indicators have been applied in order to get a comprehensive picture. These indicators are the global warming potential („carbon footprint"), the non-renewable cumulative energy demand (both described in [31]), the Swiss Ecopoints [32] (as an example of a fully aggregating method) as well as the endpoints for the three damage systems of the ReCiPe method [33] (human health, ecosystem quality and resources).

2.5 Resulting Information

The result from these analyses are – in case of electronic media – from the first study the environmental indicators per device (representing the production resp. the disposal of the various devices considered), and from the second study the indicators per unit of active use of the devices (taking care of possible upstream services, such as data transfer via routers and provisioning data on servers). For the printed media, the environmental indicators per amount of print product are calculated, showing the impact of the paper separated from the impact of the other efforts.

Based on all these results it is now possible to calculate the impacts from a variety of use schemes patterns of the printed and electronic media – simply by defining the use pattern and the print product/electronic product to be evaluated. In order to allow the user to exploit the modularity of these LCA results and to apply them easily to his or her specific media use, a web-based tool has been developed in the second phase of the project.

3. WEB-BASED TOOL

3.1 Establishing the Tool

In order to make the results available to a broader public, a website was created to be provided on the server of the "Denkfabrik visuelle Kommunikation". Therefore, we established a database containing the calculated values (LCA results, see above) and implemented the algorithms necessary to apply the data both to cases the user can specify interactively.

In the next phase of development, the design for the web tool has been established and implemented using both PHP and html. The graph-generating PHP library 'JPGraph' has been used to implement the PHP-based classes generating graphs, in order to show the calculated values. After a first prototype was implemented, a group of designers created the overall look of the webpages.

In a final step, all these elements were integrated into a website that also provides a log-in/register mechanism and a limited version of the tool available as a demo for unregistered users. In addition, tool-tips have been created to enhance usability.

3.2 Overview of the Tool

The tool can be accessed at www.denk-fabrik.ch/mat. The access is restricted to members of the "Denkfabrik" (who funded the the development) and users paying an annual fee. The demo version available for unregistered users provides only basic functionality.

Figure 3 shows a screen shot of the tool, where the basic data from our case study 1 (described below in chapter 4.1) are already filled in.

Figure 3. Web-tool mat – general overview (showing the GWP results of case study 1 described in chapter 4)

In the central part of the screen, the resulting indicators (in form of charts) of the options to compare are shown; while on the left and right side, the characteristics used for this graph are listed. These latter ones are shown in more details in Figure 4. In the left

part of this figure, the numerous input variables to define the various printed and electronic media are shown; allowing to the user e.g. a definition of two different print products in the same comparison. For the three types of computers (netbook – laptop – desktop), the same variables are used.

Figure 4. Web-tool mat – Definition part for printed and electronic media (left column), choice of LCIA indicator (right column, upper part), default use pattern for electronic media (right column, lower part)

The right column in Figure 4 shows in the upper part the choice between the available impact assessment indicators. The lower part shows the default values concerning the use pattern of the electronic media; values that can be adapted by the user simply by overwriting the default values.

4. CASE STUDIES

4.1 Advertisement of a discount shop

With the new discount food shops that entered into the Swiss market in the last years, a new wave of weekly advertisements arrived in the letterboxes of the Swiss households. In the same time, these companies started to advertise on the television and to use the Internet as another channel to reach their potential clients. Thus, their (weekly) advertisement can be used as an example to show the impacts of the various media channels that are covered by our tool. Table 6 shows the here applied use pattern for the different types of media.

To compare the three channels, we calcualted the following impact categories with **mat**: Global Warming Potential (GWP) and the three ReCiPe endpoint indicators (human health, ecosystem quality, and resources). For the use pattern of the various electronic media, the default values (as shown in Figure 4, right part) are used. In addition, for the use of the various electronic devices, a use in Switzerland is assumed (i.e. Swiss electricity mix is used for the use phase).

Table 6. Use pattern for the different media for case study 1, advertisement of a discount shop

Print Version	▪ 8 pages, format A4, 56 g/m^2 LWC paper, with 1.2 reader per copy ▪ reel-fed offset printing ▪ delivery: 150 km, by lorry
All electronic devices, except television	▪ 15 min active use (download time included); ▪ Download of 0.5 MB
Television	▪ Advertisement of 3 min

The results are shown in Figure 5 and Figure 6 below, representing two different ways of presenting the results (i.e. either the details of each life stage or the total impact only).

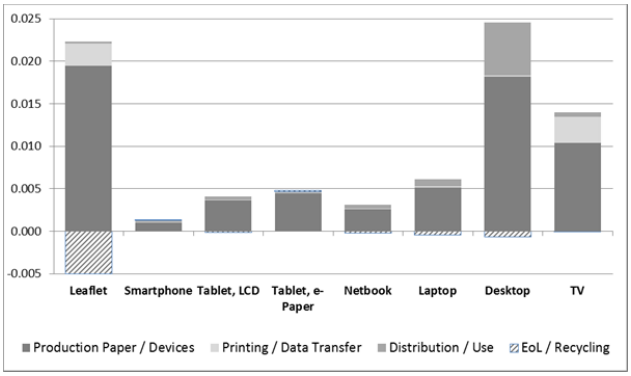

Figure 5. Case study 1, advertisement of a discount shop: Global warming potential (GWP) in kg CO_2 eq per advertisement campaign and household

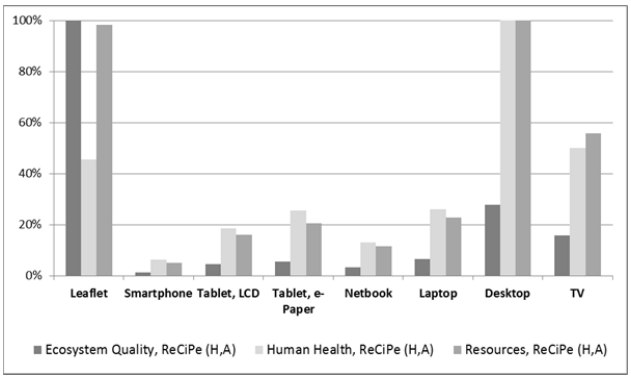

Figure 6. Case study 1, advertisement of a discount shop: Impact in terms of Ecosystem Quality, Human Health and Resources according to the ReCiPe method (in % of the highest impact each) for a single advertisement campaign

It can be seen that the three communication channels for advertisement that have the highest environmental impact are the printed version (indicated as "leaflet" in the two figures), the

television and the desktop computer. All mobile devices have an impact that is clearly lower.

In order to support the user in interpreting the results, the tool provides a comparison with the impact of one (or several) cups of capsule coffee. The data for this benchmark are taken from a simplified LCA study about coffee capsules established in Spring 2011 and published as a press release by Empa [34]. In Figure 7, the impact of one cup of coffee has been added to the presentation of the results.

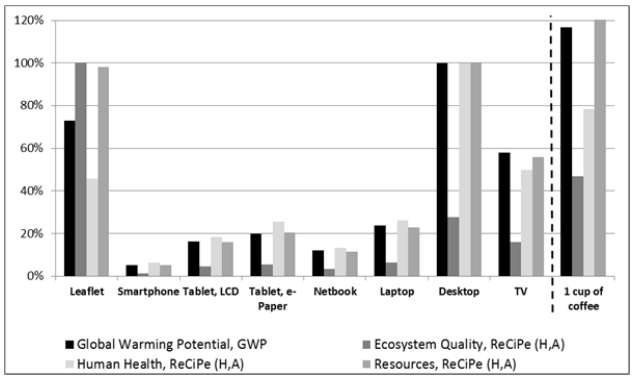

Figure 7. Case study 1: comparison of the results from the two figures above with the impact of 1 cup of coffee

As shown in Figure 7, even the way of advertisement with the highest impact is in case of the Global Warming Potential and the Resource consumption (according to ReCiPe endpoints) still lower than the sole impact of one cup of coffee. Comparing only the printed version with the cup of coffee shows that only in case of the factor "Ecosystem Quality" (according to ReCiPe), the impact from the coffee is lower – in all other cases, producing a single cup of coffee has a higher impact than the leaflet.

4.2 The impact of the paper at hand

As another illustrative example, the conference paper at hand shall be used. You may either read a hardcopy of the paper printed on a LWC paper by a digital printing process and delivered to you, read the pdf-File directly on your electronic device, or you may have downloaded the file and then printed the document (maybe after having read the abstract on the screen) on your private (laser) printer for reading the full text on paper. We will call the purely electronic option "Option 1" and the combination with private printing "Option 2".

In this case study, smartphone and television were not taken into account because we consider them unsuitable for reading such a paper. For the (professional) print option and the two electronic options, the parameters have been set according to the information summarized in Table 7.

We calculated the impact categories Global Warming Potential (GWP) and ReCiPe-Endpoints (human health, ecosystem quality, and resources); using in a first attempt just the default use pattern for the various electronic media. The results are shown in Figure 8 and Figure 9.

Table 7. Use pattern for the different media for case study 2, the paper at hand

Print Version	▪ 8 pages, format A4, 80 g/m^2 LWC paper, with 1.0 reader per copy ▪ digital printing, ink-jet technology ▪ delivery: 80 km, by train
Tablets, Netbook, Laptop, Desktop	*Option 1* ▪ 30 min active use (download time included); ▪ Download of 2.0 MB; ▪ no printing
Laptop, Desktop	*Option 2* ▪ 10 min active use (download time included); ▪ Download of 2.0 MB; ▪ printing, one-side, on recycling paper

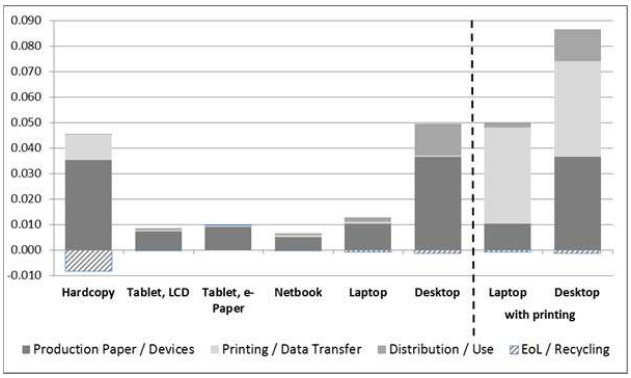

Figure 8. Case study 2, the paper at hand: Global warming potential (GWP) in kg CO_2-Eq for 8 pages

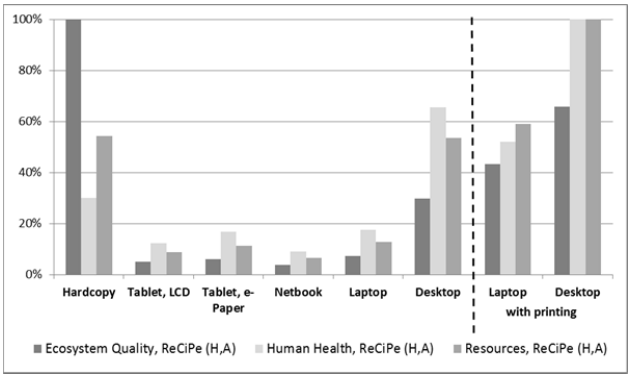

Figure 9. Case study 2, the paper at hand: impact in terms of Ecosystem Quality, Human Health and Resources according to the ReCiPe method (in % of the highest impact each) for 8 pages

Figure 8 shows that – assuming the default use patterns – the impact from a hardcopy is in the same order as reading this paper on a desktop computer (on the screen), or printing it out via a laptop computer. The three damage categories reported in the ReCiPe method (see Figure 9) show a rather similar picture (with the category 'Ecosystem Quality' showing a high impact for the hardcopy due to the land-use impacts from the forest). Again, as for case study 1, the mobile ICT devices (tablet, netbook, laptop)

– when used for reading the pdf-file – show a clearly lower environmental impact than the paper version.

The tool makes it also possible to change the various use patterns of electronic media in order to see the influence of user behaviour on the results. Here, the changes summarized in Table 8 have been applied in order to examine this aspect.

Table 8. Changes in the use pattern for case study 2, the paper at hand, in order to examine the influence of the user behaviour

Tablets	▪ LCD Tablet: life span reduced from 2 years to 1 year; no other changes. ▪ e-Paper Tablet: daily "active" rate reduced from 2 hours to 30 min, no other changes.
Netbook, Laptop, Desktop	▪ use of European electricity mix instead of the Swiss electricity mix for use phase, no other changes.
Laptop, Desktop	▪ life span reduced to 2 years for laptop and to 3 years for desktop computer, no other changes.

In Figure 10, the results of these variations are shown by the grey bars added on the top of the black bars, representing the results from the Option 1 case (no printout).

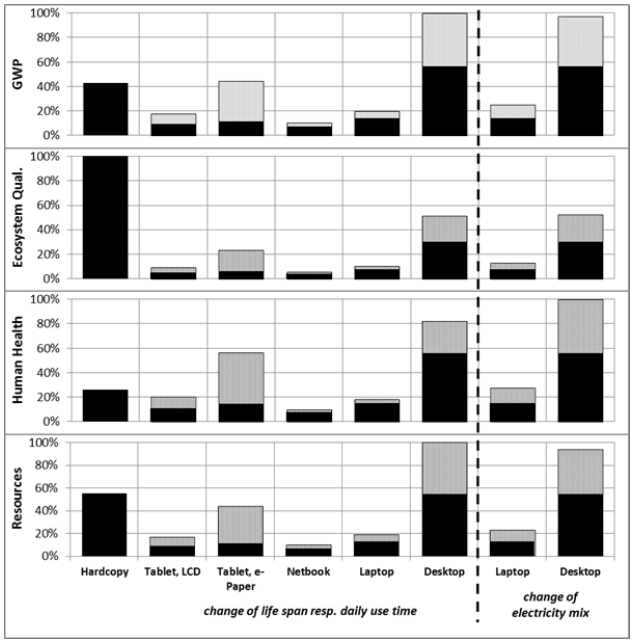

Figure 10. Case study 2, the paper at hand: influence of changes in use patterns and the electricity mix in the use phase on the results for reading 8 pages

This figure shows – almost independent from the impact indicator chosen (as all four factors show a similar picture) – a clear influence of the changes to the use patterns on the overall results. For the two tablets, the changes show more or less a proportional influence (i.e. a factor 2 for the LCD tablet due to a 50% smaller life span / a factor of 4 for the e-Paper tablet due to the 4 times smaller, daily use-time), because a larger share of the life cycle impact of the device is now allocated to its use for reading this paper, whereas the influence of the electricity mix is small. This is a consequence of the fact that the impact of these types of devices is clearly dominated by their production – and not the energy consumption during use.

5. CONCLUSION

The web-based tool **mat** supports the user to assess the impacts of various information and communication media in a very differentiated form, including the explicit consideration of use patterns of electronic devices. Not only LCA specialists, but also other user groups can apply **mat**, which has been designed mainly for professionals from the communication industry.

The tool has been presented to the members of "Denkfabrik visuelle Kommunikation" and the media at an official event in June 2012 and got public at the same time on its website (www.denk-fabrik.ch/mat).

6. ACKNOWLEDGMENTS

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